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SOME TYPES OF DEFECTS IN THE STATIC MOLDING OF TECHNICAL CERAMICS

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The long-term experience of the author in the field of ceramic molding technologies is summarized and can be used by specialists for upgrading technologic processes in industrial ceramic production and for improving product quality.

Apart from standard static molding, there exist new molding methods: vibration, impact, dynamic, hydrodynamic, explosive, electric pulse, isostatic, and quasi-isostatic molding. The latter method developing conditions for volumetric compression is the most perfect method for ceramic molding [1 – 4].

The quality of ceramics primarily depends on the correct choice of a molding method and schedule, clear definition of the technological process parameters, and, to a large extent, on compliance with technological regulations.

In selecting a molding method for a particular product range, one should take into account the following factors: configuration and size of articles, technical requirements, including these imposed on size accuracy, etc.

Long-term experience in the field of technology of molding technical ceramics, such as porcelain, steatite, ultraporcelain, aluminum-oxide and high-alumina materials, polycor, glass ceramics, and various chamotte mixtures made it possible to summarize the reasons for the emergence of various types of defects in the production of ceramics. It is established that defects mostly arise due to violation of molding technology regulations and operating regimes of molding machines or due to drawbacks of molds committed in designing or manufacturing molds. The most common types of defects in static molding are: stratification, nonuniform density, insufficient compression, low mechanical strength of molded articles, instability of sizes, cracks, nonuniform walls, ellipsoid distortions, breakage and crumbling.

Stratification. Stratification cracks are among the most common types of defects. They arise after molding pressure is removed due to expansion of pressed-in air. Excessive molding pressure in the pores of an article at final molding pressure may reach several tens of atmospheres. After molding pressure is removed, pressed-in air tends to instantly eliminate the existing pressure difference and by means of its elastic energy stratifies the molded article.

Consequently, special attention in molding should be paid to removing air from molding powder (air content constitutes 60 – 70%) and from the article in the course of molding. There are different methods for removing air from molding powder: briquetting, vacuum treatment, vibration, etc., making it possible to increase the bulk mass of powder or the density of powder poured into a mold.

Air removal in the course of molding is accomplished by developing stewise pressure, whereas specific pressure at the first stage should not exceed 0.5 – 2.0 MPa. A positive effect is produced by exposures at the final molding pressure. The cyclogram of an automated press machine should be adjusted with respect to a particular product range, since molding process is implemented at high rates.

Practical experience in molding ceramics confirms that a decelerated molding schedule increases the density of the molded article due to easier air removal, facilitates more complete consolidation of material, and, furthermore, ensures partial relaxation of stresses arising in it. Therefore, hydraulic presses have the most extensive application in the production of ceramics and refractories.

Existence of clearances for air removal between the matrix and the punches contributes to elimination of cracks. It is advisable to deposit notches on the punch and the pusher, which start on the flat surface of the punch and continue to its lateral surface. In molding low-voltage and regulating porcelain products, the notches are deposited on the working surface of the matrix as well. The depth of the notches should be 0.2 – 0.3 mm, their angle 30°, and spacing 1.0 – 1.5 mm (Fig. 1).

Granulated molding powder that has higher air conductivity than non-granulated powder is used to avoid stratification cracks.

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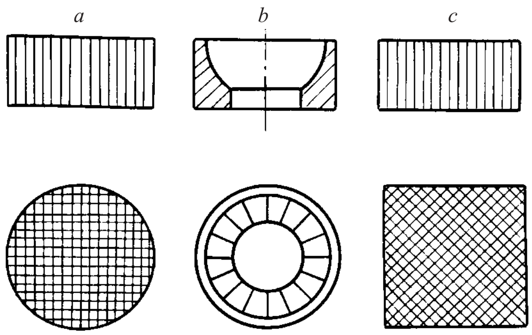

Fig. 1. Position of notches on cylindrical (*a*), profiled (*b*), and flat (*a*, *c*) surfaces.

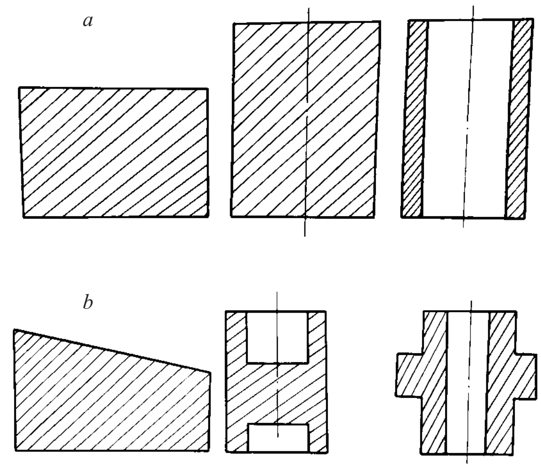

Fig. 2. Examples of articles with sections of equal height (*a*) and unequal height (*b*).

Freshly prepared molding powder facilitates the formation of stratification cracks in molded articles; therefore, it is recommended to store freshly prepared powders in normal conditions for at least 24 h. At the same time, the storing conditions should ensure the preservation of a stable content of the technological binder.

It should be specially noted that vacuum treatment of molding powder before molding, as well as vacuum treatment and development of vacuum in the course of molding, totally exclude the probability of formation of stratification cracks even in the compression of finely dispersed and hardly moldable materials.

Preliminary vibration of powder poured into a mold ensures partial removal of air (over 30%), which facilitates producing molded articles of high quality.

Apart from the specified factors, one should bear in mind that stratification cracks may arise for other reasons. For instance, insufficient rigidity of molds under the effect of lateral forces may cause squeezing of articles or crack formation in them. In certain conditions this factor is the crucial one. Such unfavorable consequences are caused by intense wear of the mold matrix walls or skewness in the pressing mechanism.

It should be noted that any of the above reasons, even when stratification cracks are not visible, causes internal stresses and anisotropy of structure in molded articles and impairs their physicomechanical and other properties.

Nonuniform density. Concerning nonuniform density in molded articles, two main types of products are distinguished in ceramic technology: articles with any equal-height section and profiled articles with unequal height of the section (Fig. 2).

In molding articles with a uniform-height section, the compression coefficient of molding powder remains equal in all sections. In this case a cause of nonuniform density can be pressure losses caused by overcoming external friction of the ceramic mixture against the mold walls: the further from the punch, the lower the density.

Static molding of profiled articles, where molding powder is poured into a mold with an equal height over the whole surface area, leads to an unequal powder compression coefficient due to the article geometry. If the powder does not acquire sufficient fluidity under the effect of pressure, the mixture cannot be redistributed in accordance with the product geometry, and then a nonuniform compression coefficient is the main reason for nonuniform density. Nonuniform density causes high stresses in articles and in firing produces deformation due to nonuniform shrinkage [5].

Molding articles with relatively large protrusions and depressions is permissible only in the case of equal compression coefficients of the molding powder in each zone (step) of the article molded. This can be accomplished by using differential-pressure molds, where each step is molded using a different punch. The resulting articles have uniform density at the periphery and in the depressions. Therefore, molding articles with unequal-height sections requires special attention in selecting the molding scheme and conditions,

Nonuniformity of density in molded articles can be caused by a loss of applied pressure due to external friction, which in some cases reaches 80%. This leads to nonuniform shrinkage in sintering, which, in turn, causes warping of articles and formation of cracks. Under unilateral static pressure, conicalness may arise in a fired article.

Static molding is not used to compress articles of substantial height. Long-term practical experience in molding has shown that unilateral application of pressure is suitable for molding articles 25 – 30 mm high from nonplastic materials, and pressure applied to two sides can mold articles 50 – 60 mm high, regardless of the cross-sectional area. In molding articles from plastic materials this height can be increased by 50 – 60%. Higher articles should be molded using the technology of quasi-isostatic molding.

Molds for static molding with one-sided pressure application are mainly used to mold flat articles of small height and also to mold articles with protrusions or depressions (oriented in the direction of pressure application) of thickness equal to $1/4 – 1/3$ of the total thickness of the product for

low-plasticity materials and up to 0.6 – 0.8 of the total thickness for plastic materials.

To prevent nonuniform density of materials in static molding, two-sided pressure application is used, where additional compression of the article on the other side can be effected either by a mobile floating mechanism of the press itself, or in a mold with a floating matrix. In both cases a prerequisite for high-quality products is applying equal pressure on both ends of the product in molding. The neutral pressure plane in this case should pass via the center of the molded piece, otherwise the effect of two-sided compression is reduced.

It should be noted that when pressure is applied simultaneously to two sides of an article, i.e., by two molding punches simultaneously, both sides are compressed equally. However, the density in the middle size is significantly lower, since air under compression is pushed into the middle part of the article and becomes pressed inside it. Consecutive application of pressure, first by one punch, then by the other provides for better consolidation and more uniform density distribution in the article.

The duration of pressure application duration as well affects the uniformity of density and structure in products. As the pressing duration grows, the density uniformity increases and the quality of the end product improves due to removal of a greater quantity of air from the mixture, whereas elastic stresses in the mixture transform into residual stresses. Otherwise after pressure is removed, elastic expansion contributes to the formation of stratification cracks.

Nonuniform density can be also caused by nonuniform charging of molding powder into the matrix. A nonuniform distribution of powder in the matrix plane results in more condensed zones forming in the article on elevated sites under compression, whereas the other zones due to insufficient fluidity of molding powder under pressure have lower density.

Such nonuniform density is especially typical of compressing flat articles of low height (such as disks). As the section size grows, the nonuniformity of density increases as well. To eliminate this defect, molding powder should be flush-loaded and the surface of the powder should be leveled with a metallic ruler, first in one direction, then in the other direction from the central line of the molding powder plane.

The main factor responsible for producing articles with uniform density is homogeneity of the mineral and granular compositions of molding powder and the content of temporary technological binder.

The content of technological binder in ceramic molding powder is one of the main factors in the molding process. With increasing content of binder in the powder, the mechanical strength of molded and fired articles increases and the difference in density along the height of the article decreases due to the decreased coefficient of friction against the mold walls. Furthermore, with an increasing quantity of technological binder, the specific molding pressure and fire shrinkage coefficient of molded articles decrease significantly.

The quality of articles depends not so much on the molding pressure level but on the content of the technological binder. Therefore, its is advisable to lower the molding pressure substantially by appropriate selection of the composition and quantity of the binder. An optimum content of technological binder in molding powder and a particular pressure level are selected for each material.

In plastic materials water acts as a binder.

For nonplastic materials (aluminum oxide, high-alumina, polycor) research was carried out to select an optimum composition of technological binder. Over 25 different binder compositions were investigated. They included paraffin (medicinal, match, powdered, and liquid paraffin), wax, ethyl alcohol, glycerin, solution of caoutchouc in benzine in different ratios, dextrin, polyvinyl alcohol, tragacanth gum, starch paste and flour paste, etc.)

The results of these studies indicated that the optimum binder for ceramic materials specified is a mixture containing 70% aqueous 10% solution of polyvinyl alcohol and 30% glycerin. The optimum quantity of this binder constitutes 10% of the total molding powder weight. A special advantage of this binder compared to other binders is the absence of mineral impurities (ash content) and a very high binding capacity. Freshly molded articles have sufficient mechanical strength for subsequent technological operations and dried articles have high mechanical strength allowing for machine treatment. Furthermore, such binder ensures the stability of properties of molding powder in long-term storage and allows for molding without additional lubrication of molds.

Molding powders based on this binder have better mobility under compression and better moldability compared to other binders studied.

The use of the polyvinyl-glycerin binder made it possible for miniature ceramics made by static molding and some articles produced by quasi-isostatic molding to be fired immediately after molding, without additional drying and souring operations [5].

Insufficient compression. Insufficient compression can occur as if the punch in molding stops transmitting the force of the press to the material, since the punch gets stuck at the sides of the matrix or at the inner wall of a conical matrix. In both cases the manometer shows a required pressure value, but the article has a loose structure, since pressure is transmitted not to the material but to the metallic parts of the mold.

In view of this, a new mold installed on a press should be checked by measuring the punch diameter and checking its correspondence to the matrix diameter at the final depth of the punch immersion. One should also check the presence of a clearance between the punch and the bottom end of the matrix.

Insufficient compression of articles may arise due to an insufficient quantity of molding powder poured into the mold matrix, or in the case of faulty operation of the weigher, for instance, proportioning insufficient powder quantities.

Low mechanical strength of molded articles. One of the main reasons is insufficient molding pressure. This may occur due to fluctuations in the technological parameters of molding powders, such as binder content, compression coefficient, or granulometric composition and also depends on the method of powder preparation and molding regimes.

Compared to other methods for molding ceramics, for instance, plastic molding and cold and hot casting, static molding ensures better control of mechanical strength and density of molded articles by means of varying molding pressure. This is a significant advantage of this method.

Steady mechanical strength of molded articles in industrial conditions can be achieved by constant monitoring of the specific molding pressure (2 – 3 times per shift) and the properties of each powder batch prepared with respect to its bulk mass, granulometric composition, and technological binder content.

If the parameters of molding powder deviate from prescribed values, the molding pressure has to be adjusted.

Instability of sizes. Deviation of article sizes from prescribed sizes (when an article after molding, drying, and firing is larger or smaller than a prescribed size) occurs due to sharp fluctuations in technological binder content and wear of molds. This defect can be caused by deviations in the mixture composition or excessive milling of its grog component.

The measures intended to avoid deviation of sizes in molding include compliance with a preset content of technological binder in molding powder and replacement of worn mold parts. Furthermore, the composition and dispersion of the initial mixture should be strictly monitored.

Size deviations are observed most frequently in making products from non-granulated powders, due to instability of their compositions. The presence of a high quantity of the dust-like fraction in powder, which is poorly condensable, contributes to obtaining articles with substantial shrinkage.

Articles, to which stringent requirements on size accuracy are imposed, should be molded according to regimes ensuring stability of their shrinkage coefficients. It is advisable to introduce a minimum quantity of plastifying additives. Furthermore, it is better to replace volatile plastifiers by non-volatile agents to prevent variations in their content in the course of the technological process.

In practice, in order to obtain precise sizes, prototype products are made and fired, shrinkage coefficients are determined corresponding to particular batches of molding powder and particular process regimes, and then, if necessary, the molding regimes or mold sizes are adjusted.

Cracks. This type of defects is one of the most common. Cracks can be diverse: longitudinal, cross-lateral, lattice-like, radial, arranged at an angle, etc.

One of the main reasons for crack formation is the effect of two perpendiculars forces in an article pushed out of the matrix: elastic expansion of the molded article itself and the compressive force of the matrix. To eliminate these factors, it is necessary to ensure:

– homogeneity of the molding powder prepared;

– uniform filling of the molding powder inside the matrix volume, especially in molding articles of complex configurations.

– uniform density of the molded article across its section;

– conicity of the working surface of the matrix, which should start from the bottom end of the article compressed;

– optimum pressure values;

– pushing articles from the mold without stopping;

– use of lubricants to decrease the effort of pushing the article from the matrix;

– displacement of pushers strictly parallel to the molding axis.

The quality of molded articles to a large extent depends on the mold design, the quality of its metal manufacture, and the reliability of the molding equipment.

Substantial wear of the working part of the matrix produces cracks in the article when pushed out of the mold. An excessive binder content in molding powder as well leads to crack formation, since it impedes contact between particles.

A crack lattice on the surface of a molded article may be caused by heterogeneous distribution of moisture among individual grains of the molding powder, which determines nonuniform shrinkage after molding. As a consequence, very fine cracks are formed, which later increase in size and are arranged in the form of a typical lattice on the surface of the article.

This type of defect is not always manifested immediately after molding. Sometimes, it is discovered only after firing and mistakenly attributed to firing-related defects. Preparation of molding powder in compliance with preset parameters fully eliminates this type of defect.

Radial cracks around holes made in articles are found frequently enough and emerge for the following reasons:

– deflection of pin-marks shaping the holes, which is due to imperfect coaxiality of the punch and the pusher openings;

– existence of a sag (deviation from a straight line) in the marks shaping holes in articles;

– insufficient smoothness of the mark surface;

– absence of conicity on the marks and radii (small curvature).

To eliminate this defect, it is necessary to increase the precision of coaxiality of the punch and the pusher, to manufacture mold parts as a set (the punch, the pusher, and the mark holder), to improve the smoothness of mark treatment, to ensure its conicity, and to introduce control of diameter and rectilinearity of the marks.

Nonuniform walls. Nonuniform walls (unequal wall thickness after molding) arises due to imperfect coaxiality between the matrix and the punches in the mold. To avoid this, the mold should be center-aligned.

Nonuniform wall thickness may also arise due to swinging of the press slide bar caused by its wear. In this case the press guides should be adjusted or replaced.

One of the most effective methods for avoiding this defect is using molds with guide columns.

Ellipsoid distortions. Ellipsoid distortions are formed in molded articles in the course of firing. A crucial role in firing is accurate alignment of articles in saggers.

To avoid an article being fused to a sagger, dry quartz sand, alumina, or electrocorundum are placed on the bottom of the sagger, depending on the mixture composition and temperature. Such filling material should not contain iron impurities to avoid fusion with the sagger bottom, which delays shrinking on such spots and in general produces ellipsoid distortions in the article.

Filling material under the article to be molded should be placed as a single layer of grains, i.e., a monolayer, to ensure free rolling of the article over the filler grains toward the center in firing, which provides for uniform shrinkage of the article in firing and significantly decreases or eliminates ellipsoid defects.

If the filling material is simultaneously needed to level the sagger bottom, the article to be fired should be placed on the filling and reseated to ensure a uniform filling layer along the entire bottom of the article. To verify the uniformity of the filling layer, the article after fitting-in should be slightly raised and, if areas are detected where the article does not seat on the filling layer, more filling material should be added, and then the article should be reseated anew.

To obtain an article with minimum ellipsoid distortions, it should be fired on special supports made of the same material as the ceramic article and profiled to fit this article. The shrinkage coefficient of these supports should be higher than the shrinkage coefficient of the product, i.e., the density of the support after molding should be lower than that of the product. This difference in shrinkage coefficients is needed for the support to compress the product toward its center. With a reverse relationship of shrinkage coefficients, the product will be stretched by the support along the bottom end adjacent to the support.

It should be noted that static molding technology, easier than any other molding method, makes it possible to modify the density of these special supports by varying molding pressure applied. However, it should be taken into account that articles, for instance, rings of height 100 and 150 mm and ring-shaped supports for these articles that are 20 mm high, although compressed under the same specific pressure, have different shrinkage coefficients. Therefore, pressure for molding special supports should be selected based on a particular article and not based on optimum molding pressure of a particular ceramic mixture.

Breakage or crumbling of molded articles may be related either to imperfect mold design or to negligence of the operator. It should be noted that defects arising in molding are virtually impossible to eliminate at subsequent stages of the process.

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